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THE PRESCOTT SCALE, MATSUCOCCUS VEXILLORUM MORRISON, AS ASSOCIATED WITH BRANCH KILLING ON PONDEROSA PINE IN THE SOUTHWESTERN UNITED STATES (HEMIPTERA-HOMOPTERA)

by
Howard L. McKenzie
Bureau of Entomology and Plant Quarantine

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THE PRESCOTT SCALE, MATSUCOCCUS VEXILLORUM MORRISON, AS ASSOCIATED WITH BRANCH KILLING ON PONDEROSA PINE IN THE SOUTHWESTERN UNITED STATES

(HEMIPTERA-HOMOPTERA)

By Howard L. McKenzie
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INTRODUCTION

A conspicuous type of branch killing or branch flagging, commonly known as "twig blight", has been observed for the past 20 or 25 years on ponderosa pine (Pinus ponderosa var. scopulorum Englemann) trees in Arizona, particularly around the vicinity of Prescott. The files of the Prescott National Forest contain reports indicating that this type of injury has been noted at various times during this period.

About 1933 the prevalence of this injury attracted widespread attention on the part of the local residents of the city of Prescott and other communities in this National Forest, and the Forest Service was requested to take action toward an investigation of the trouble and to employ eradication measures if such could be developed. This lead to a considerable amount of effort on the part of the Bureau of Plant Industry to determine whether or not a plant disease was the cause. Attention was later directed toward the possibility of insects as the primary agency involved. This lead to the investigations undertaken in 1936 by the Forest Insect Division of the Bureau of Entomology and Plant Quarantine which forms the basis of this paper.

The following summary of developments leading up to this study has been prepared by Dr. F. C. Craighead, in charge of the Division of Forest Insect Investigations.

In the spring of 1934 a report was submitted by N. Ponomareff (a foreman in a CCC camp, who was supervising control work against the twig blight on the Prescott National Forest), in which he claimed that the Prescott twig blight was of insect origin and that aphids were responsible. Dr. Hartley, of the Division of Forest Pathology, feeling that the evidence on the fungus was incomplete, called this report to the attention of Dr. F. C. Craighead, of the Division of Forest Insect Investigations, and Mr. E. E. Carter, of the Forest Service, and the three of them discussed it at some length. Dr. Craighead indicated that on the basis of similar injury produced by such sucking insects as Chermes, Adelges, and Cryptococcus, and by Monochamus feeding scars, an insect injury hypothesis was easily acceptable.

Following this conference it was arranged that Dr. M. W. Blackman and Mr. J. M. Miller meet with the local pathologists on the Prescott National Forest in June of 1934. This resulted in a plan to check on the aphid theory during the season 1935. The study was carried out by Dr. A. S. West, who definitely discredited the connection. In May 1935, specimens of Matsucoccus on the twigs of ponderosa pine at Prescott were collected by an employee of the Division of Forest Insects and were sent to Washington for determination. They were referred to Dr. Morrison but in the routing procedure followed in handling this material, he did not reach these specimens until after he had seen those of Dr. Davidson (next paragraph).

In January 1936, Dr. Ross W. Davidson, Division of Forest Pathology, who was making a close scrutiny for insects on material received at the Washington Office, discovered the presence of a very inconspicuous insect on the pitch-soaked parts of blighted twigs, and Dr. Hartley requested Dr. Craighead to look at these specimens. They were recongized as scale insects and Dr. Harold Morrison was called in. He identified and later described[1] them as a species of Matsucoccus scale of the family Margarodidae and in a discussion pointed out that the eastern species was known very definitely to kill the terminal portions of twigs of pine trees.

This coincidence confirmed Dr. Craighead's suspicions that this insect was causing the disease. This led up to a field examination by Dr. Morrison, Dr. Craighead, and Dr. West on April 23 to 27, 1936, which was sponsored by the Forest Service. Messrs Q. Randalls and Carter of the Forest Service were also present.

At this field conference evidence was developed strongly supporting the theory that Matsucoccus was definitely involved with the flagging of the ponderosa pine twigs. It was therefore agreed that further study and experimental work should be directed toward this insect. Dr. Morrison remained for several weeks to help Dr. West set up the experimental program, one of the most important features of which was the transfer of living Matsucoccus females to pine twigs in unblighted areas. This will be reported on later.

Several things were pointed out in the report of this examination, prepared by Dr. Craighead, which later developments verified, namely:

(1). A striking correlation existed between the distribution of Matsucoccus and that of the blight.

1--1939. Morrison, H. Descriptions of new species of Matsucoccus (Hemiptera: Coccidae). Ent. Soc. Wash., Proc., 41:1-20

(2). That there is a marked similarity between the lesions on the flagging twigs and the pitch infiltrated scars produced by the feeding of other insects, or even by mechanical injury, such as hail.

(3). That in all probability the flagging of these twigs would in itself exert a high degree of control on the scale insect and for this reason the apparent good results from control operations might not be really significant.

The investigative work begun in 1936 was continued through the seasons of 1937, 1938, and 1939 and forms the basis of the present report.

GENERAL DESCRIPTION OF FLAGGING INJURY

Damage to the ponderosa pine branches is usually noticeable first in the early spring. Flagging has been observed as early as January, as was the case in 1934. Branches continue to flag during the summer and even into the fall of the year. The flagging condition occurs predominantly in the upper crowns and may be present on trees in any state of health from vigorous to weak. Leaders one and a half inches or more in diameter, and four feet or so in length, will oftentimes be killed. (Figure 1). Flagging

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Insert Figure 1

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of terminals is common. The first evidence of a dying branch is the gradual fading of the needles from base out, so that they assume a light pea-green color. The needles gradually droop, turn yellow color and die. The dead needles usually remain intact on the branches for several months, although within a year most of them will have fallen off. Occasionally some retain dead needles into the following year.

A pine tree that has recently flagged, and particularly one that has flagged heavily, will appear to be worse than it actually is. The tendency is to overestimate the percent of flagged branches as compared to the remaining green ones on the tree and this is probably due to the fact that the yellow flags are so conspicuous against the dark green needle background. One particular tree, located on one of the study plots on the Prescott National Forest, that looked practically dead at the time, was flagged only 66 percent by actual count. Records indicate that this tree is recovering.

A critical examination of dying branches, made by cutting into them, reveals at least one primary lesion (Figure 2), usually impregnated

Insert Figure 2

with pitch, that completely girdles the branch. This lesion commonly exists on the third and fourth internodes, although many have been observed on the other internodes of the twigs up to the sixth. Many incomplete or partial lestions may be found on Matsucoccus infested green branches, and it is believed that some of these may spread and eventually kill the affected branch when proper conditions exist.

Flagged trees characteristic of the type on the Prescott are by no means restricted to the forests in this region, but have been observed elsewhere in Arizona and New Mexico. In these areas the same species of scale Matsucoccus vexillorum Morrison was noted on flagged branches. Flagging identical in every respect to this has not as yet been found in California, and this may be due to the fact that this particular scale insect has not been found in this region or that the host species does not occur in the pine stands of this state.

The relation of the scale, Matsucoccus vexillorum Morrison to flagging injury on Pinus scopulorum in the areas around Prescott, Arizona will be shown in later sections of this paper.

Relation of Other Margarodid Scale Insects to Similar Types of Injury

Certain species of the coccid family Margarodidae have been reported by various authors as inflicting considerable injury on economic plants. The cottony cushion scale, Icerya purchasi Maskell, has attained a tremendous notoriety as a pest since its initial introduction into California about 1870. Other genera of reported economic importance include some Margarodes attacking grapevine roots in South Africa and South America; Xylococculus causing damage to the bark of yellow birch in the Great Lake region of North America; a number of species of Drosicha injurying a variety of economic plants in the eastern Asiatic region from India to Japan, and so on.

Several species of Matsucoccus are known definitely to cause injury to pines. Matsucoccus acalyptus Herbert has been reported as early as 1921[2] as doing damage to single-leaf pinon (Pinus monophylla) in Idaho,

(2) 1921. Herbert, F. B. The genus Matsucoccus with a new species. (Hemip.-Homop.). Ent. Soc. Wash., Proc. No. 1, 23: page 22, paragraph 3.

and the present author observed this same species causing extensive flagging to Pinus edulis on the south rim of the Grand Canyon in Arizona during the 1938 summer season. In 1928 Morrison[3] reported one species of Matsucoccus as causing gall-like pits on pine twigs, and doing appreciable damage to some ornamental plantings. This species was later described by Morrison as Matsucoccus gallicolus and its host was recorded as Pinus rigida. More recently other species of Matsucoccus have been observed by the writer causing both stem and foliage injury. These are, Matsucoccus paucicatrices Morrison, on sugar pine in California; Matsucoccus fasciculensis Herbert[4] on digger and ponderosa pines in California; and Matsucoccus bisetosus Morrison, M. californicus Morrison on ponderosa pine in California. Injury to twigs and stems somewhat resembling Prescott flags are not uncommon in forest areas.

(3) 1928. Morrison, H. A classification of the higher groups and genera of the coccid family Margarodidae. U. S. Dept. Agr. Tech. Bull. 52:1-240. Illus.

(4) 1919. Herbert, F. B. A new species of Matuscoccus from pines in California. (Hemip.-Homop.). Ent. Soc. Wash., Proc. 7:157-161.

SEASONAL HISTORY OF THE SCALE, MATSUCOCCUS VEXILLORUM MORRISON

The information regarding the seasonal activities of this insect and its effects upon the host tree was secured both by field observations and insectary controlled rearings in the vicinity of Prescott, Arizona. A preliminary survey of Pinus scopulorum areas in Arizona and New Mexico and collections made by the office of Forest Pathology has served as the basis for known distribution of this insect.

Distribution and Hosts

The geographical range of Matsucoccus vexillorum Morrison appears to be general throughout the forested areas of Arizona and New Mexico. Definite locality records exist showing that it is present on the Prescott, Coconino, Sitgreaves, Apache, Gila, Coronado, Cibola and Santa Fe National Forests (see accompanying map, Figure 3).

Insert Figure 3

The only known host of this Matsucoccus scale is Pinus ponderosa var. scopulorum Englemann. It is apparently quite specific in its host preference as no specimens have been collected from any other species of the genus Pinus.

Adult Female Scale

Description: In general appearance the adult female scale is rather robust and elongate with the posterior end of the body somewhat broader, (Figure 4). This stage is approximately 3/16 of an inch in

Insert Figure 4

length, has paired leg appendages, is brown in color, and continually manipulates the 9-segmented antennae, feeling its way cautiously over the wood surface. No functional mouthparts are present, and as a consequence feeding does not take place during this stage.

Habits: During early spring, usually April, of each year, many hundreds of these brown adult females (see pictorial plate, Figure 4) may be observed shoving their way out of the overwintering intermediate or preadult bodies. Their actions are sluggish and at first it appears as though they might settle any place on the branch. They may migrate several feet before they finally settle down. It will soon be noted that they definitely prefer to settle at the nodes, principally on the underside, crowding against and on top of one another in large numbers (Figure 5).

Insert Figure 5

Occasionally they will be found settling on some twig killed by tip moth or any sort of crack or crevice that affords them ample protection. Soon after settling wax is profusely secreted, and as the eggs are extruded, the abdomen is gradually retracted or withdrawn into the thoracic (forepart) region of the adult female, thus forming a kind of invaginated marsupium. Figure 4 shows a rather incompletely invaginated pocket. It appears as though the whole body has been modified for the reproductive function. By the time the eggs are laid, and this is usually within 4 or 5 days, the secreted wax filaments are so intertwined that practically the entire body of each female is covered, and when these females congregate about the nodes they present the appearance of small tufts of cotton. Eggs are to be found in the marsupium as well as in these waxy secretions.

Population counts of the mature females after they have settled in these cottony masses indicate that they apparently prefer to settle about the nodes rather than on the internodes. Out of 199 green branches examined, only 6% of the internodes were found to possess adult females. The actual node counts are tabulated below:

Node	Nodes examined	Females counted	Average population per node
1	199	3,110	15.63
2	199	5,670	28.49
3	199	462	2.32
Total	597	9,242	15.48

The above figures indicate that the adult females prefer to settle on the second node rather than on the first or third, and this may possibly be explained by the fact that the insects migrate just prior to the time the current year's bud starts growing, and that until this takes place and the needles become full grown, the available space for them to settle on the first node is apparently more limited than on the second node. The tendency is for them to work their way out as far toward the tip as possible and still have a node about which they may settle.

Adult Male Scale

Description: The minute winged adult male scales are seldom seen in nature. They possess the characteristic two wings and the long, white, waxy anal filaments. The males are extremely fragile, scarcely 1/16 of an inch in length, and as a consequence it is difficult to see them with the unaided eye (see pictorial plate, Figure 4).

Habits: The adult male scales emerge during early spring (usually April when the adult females are in evidence) from the intermediate or pre-adult stage. These winged males may be seen walking over the pine branches, apparently using the wings as a sort of balance. Flights of the winged males have not been seen by the author, and this is no doubt due to their relative inconspicuousness. Copulation with the migrating females was observed, however, and it can be assumed that fertilization takes place during this migrating period.

The Eggs

Description: The eggs of this scale insect are found within the marsupium and waxy secretions of the adult female. The individual egg is exceedingly small and is practically invisible to the unaided eye, although the egg mass itself is quite conspicuous. An average of 167 eggs are laid by each adult female scale. The eggs are bean shaped in appearance (see Figure 4) and are first lemon yellow, but as they incubate become a deep orange-yellow color. Prior to hatching, each egg presents two distinct eye spots, representing the eyes of the developing larva within.

Incubation period: The incubation period of the eggs of this species of Matsucoccus will vary from 12 to 23 days depending primarily upon climatic conditions. Hatching takes place usually during the month of May in the vicinity of Prescott (altitude 5,500), although at higher altitudes the incubation period may be retarded for several weeks.

First Stage Larvae

Description: The first stage larvae are oval shaped, possess leg appendages, and are but little larger than the eggs themselves. (See Figure 4). In order to see them clearly it is advisable to use a hand lens or microscope. They appear lemon yellow at first, although as they develop they will turn darker yellow-orange.

Habits: These larvae are quite active, although they soon settle under the thin layers of bark on the stem and many are to be found under the bract enclosing the needle base. Feeding takes place during this stage. Prior to the first molt there appears to be a quantity of wax secreted from the posterior portion of the body of the insect. This wax appears to be rather short filaments as contrasted with the long filaments secreted by the adult females. The first molt* occurs usually within 38 to 44 days, depending upon climatic conditions, after the young first settle. This molt occurs during the latter part of June or the first part of July in the vicinity of Prescott.

* There has been much discussion concerning this molt giving rise to an appendage second stage larva. However, experimental evidence at hand indicates that such is the case.

Second Stage Larvae

Description: The early second stage larvae resemble the first stage except that they are somewhat larger. However, they are still quite small and it is necessary to use a hand lens in order to magnify the insects enough to really see them. As far as can be determined, the leg appendages, antennae and spiracles (breathing pores) are apparently identical morphologically with those of the first stage larvae.

Habits: The second stage larvae migrate but a little distance from their previous feeding quarters and often settle practically in the same spot. They do, however, show a decided preference for and usually settle under the bract enclosing the needle base. Occasionally some are to be found in cracks and crevices of the bark layers. Once the second stage larvae settle, feeding commences. Although the early second stage larvae resemble the first stage, it is but a short time after settling (usually 6 or 8 days) that they commence swelling in the anterior portion of the body so that they rapidly assume a pyriform outline. They continue to grow and swell until finally the leg appendages are no longer of any use to the insects. The second molt occurs usually during the middle or latter part of August in the Prescott vicinity--approximately 50 days after the first molt.

Intermediate or Preadult Stage Larvae

Description: The third, intermediate or preadult stage larvae are apodous (without legs) and it will be readily observed from the stained microscopic preparations that there has been a marked change in the spiracles as compared to these structures as they exist in either the first of second stages. The preadults of the female sex are stout, nearly circular, and the derm is more of less distinctly chitinized. According to a letter from Dr. Harold Morrison there is but a slight differentiation between the male and the female in this preadult stage, and the author was unable to distinguish them. When fully mature the female preadult is about the size and shape of 5 or 6 gauge bird shot (or approximately 2 mm. in diameter), and is readily discernible with the naked eye. By far the greater number of these are to be found under the bract enclosing a needle base (Figure 6).

Insert Figure 6

Habits: The second molt giving rise to this preadult stage represents a metamorphic change in which the second stage derm finally ruptures in the anterior part (see Figure 4), and for some time the early preadult stage larvae are almost completely enclosed within this derm. Unless stained microscopic preparations are made at intervals during the scale insect's development, the new stylet or mouthpart formation that takes place prior to each molt will occur unobserved. As a matter of fact, the early splitting of the second stage derm would likewise pass without notice unless the microscopic preparations are made every few days. As the preadult grows, the second stage derm continues to split until finally the appearance is that of a derm-cup that encloses only the lower portion of the preadult stage. This derm-cup will oftentimes slough off by the time the insect has attained the fully matured intermediate or preadult stage.

Since the preadults are apodous they are forced to remain in the same place where the second stage larvae settled. No preadults are to be found on the current year's growth, with the possible exception of a very few near the first node. This may be explained on the basis that by the time the second stage larvae settle, the current growth has extended but very little and what area is available for feeding is just that around the first node. As a consequence, by far the greater number of preadults settle on the second internode, and extensive population counts have been made to substantiate this statement. The preadults are less frequent on the third internode, and are rarely observed on the fourth internode unless the tree is extremely heavily infested. On one particular green second internode, 5 inches long and .25 inches in diameter, a total of 104 preadults were counted, although the average for this size green internode was but 40. The average number of preadults for the same size green internode on the third and fourth internodes is approximately 20 and 13 respectively. On flagged twigs the scale population per second internode is two or three times as much as on green infested second growth.

The preadults, like the first and second stage larvae, also possess stylets or sucking mouthparts, and it may be assumed that during the preadult stage the most feeding occurs. It is during this stage that the scale insect passes the winter. The preadults usually do not attain their maximum size until some time in February of the following year (see seasonal history plate, Figure 4), and it is not until during April and May that the adult males and females emerge from these overwintering bodies.

PLANT TISSUES SPECIFICALLY AFFECTED BY FEEDING HABITS OF THE SCALE

It is during the larval stages that this scale feeds, and as a consequence histological sections were prepared to study its feeding habits. On the basis of these histological preparations it appears that the stylets or mouthparts of the scale insect terminate in storage cells of the cortex area (Figure 7). Of the many hundreds of histological sections made, only

Insert Figure 7

this one shows the apparent termination of the stylets in a large cortex storage cell. Other preparations show the stylets penetrated into the epidermal cells and many cases are to be found where they have reached the old cortex area, being apparently cut off beyond this point by mechanical means and not being recovered again in sections of the same series. It also appears that where the stylets have pierced through a cell there has been a coagulating substance formed around the stylet sheath. Brown's experiments[4]

(4) 1916. Brown, K. B. The specific effects of certain leaf-feeding Coccidae and Aphididae upon the pines. Ann. Ent. Soc. Am. No.r. 9:414-422.

on the feeding of various coccids upon pines indicate that when the stylets are forced into the plant tissue a sheath of saliva is formed about it. According to Carter's work[5] on the pineapple mealybug this coagulating substance

(5) 1933. Carter, W. The spotting of pineapple leaves caused by Pseudococcus brevipes, the pineapple mealybug. Phytopathology, 23:243-259.

is produced by a phytotoxic secretion. Parr's tests[6] on the "golden oak

(6) 1937. Parr, Thaddeus. Notes on the golden or pit-making oak scale. Jour. Forestry. No. 1 35:51-58.

scale", Asterolecanium variolosum Ratz., infesting chestnut oak in the eastern United States indicates that this coagulation is probably caused by the injection of salivary liquids, and that as the stylets pass through the cells, part of the cytoplasmic content of each cell coagulates around the ends of the stylets. In every instance some enzyme or toxic material came from the scale insect, and it is reasonable to assume that this is what takes place in feeding of Matsucoccus vexillorum Morrison on the pine trees in Arizona.

It has been repeatedly observed that if one will carefully cut beneath an aggregation of feeding Matsucoccus scale on a ponderosa pine branch, even where the insects have settled near the node on the current year's growth, there will usually be a brown or necrotic spot in evidence. Furthermore, if one will repeat this operation on a normal uninfested current year's growth near the node, no such spot will prevail unless some abrasion has previously taken place. The natural bark plate formation of normal uninfested growth is not greatly extended and will not be confused with necrosis beneath feeding scale. The consistent association of these spots with an aggregation of scale cannot be ignored. An examination of microscope slide preparations of wood sections showing necrotic areas found in association with Matsucoccus scale shows a very definite internal break-down of cell contents as well as cell wall disintegration (see Figure 8-A). Figure 8-B shows a wood section of normal uninfested current

Insert Figure 8

year's growth of ponderosa pine.

RELATION OF SCALE POPULATION TO LESIONS AND FLAGS

Internode Counts

Many necrotic areas produced on stems by feeding scale insects are not followed by flagging, and it has been observed that these form only a scar or partial lesion that heals over. However, there are some such necrotic spots that do cause full lesions that completely girdle and kill the twig and this is definitely proven in the discussion that follow.

During the periodic check-up of the flagging of artificially infested ponderosa pine trees on the Wolf Creek, plot 1, it was discovered that a heavy population density of Matsucoccus vexillorum existed on flagged twigs, and that a much lighter infestation occurred on the green infested twigs. During 1937, Parr (see reference 6) noted this same phenomenon on chestnut oak stems in the eastern United States infested with the "golden oak scale", Asterolecanium variolosum Ratz. Parr showed by population counts that dead stems possessed over twice the numbers of scale than occurred on green stems. Therefore a more thorough determination of scale population density on flagged and green twigs was made from infestations occurring in the field in the Prescott vicinity.

Since it has been already demonstrated by preadult population counts that the largest number of insects occur on the second year's internode (see page 16), it was decided to use this as an index for these determinations. Green and flagged twigs from infested trees were collected at random for microscopic examinations. Data were obtained from a total of 285 individual twigs segregated by internode length, and the tabulated results are presented in Table I.

Insert Table I

The data included in this table show: (1) that the population density of scale insects on flagged twigs is over twice that on green twigs, i.e. the 5 inch flagged internode possesses an average of 53.0 scale, whereas in the same length of green internode only 18.6 scale occurred*; and

* It should be taken into account that hundreds of dead scale have sloughed off the internodes of the flagged twigs with dead needles. Only 27 percent of the second internodes on the flagged twigs retained needles, as compared to 80 percent included on those of the green twigs. This fact alone would increase many fold the average number of scale per inch on flagged internodes.

(2) that flagging contributed to a high mortality of Matsucoccus scale, i.e. the 5 inch class of flagged internodes possessed an average of 48.7 dead scale, whereas in the same class of green internodes only 3.9 dead scale occurred.

Tanglefoot Band Studies

Even though it had been demonstrated through actual counts that a large population of Matsucoccus scale was always present on flagged branches, there was still the question as to whether the scale insects were definitely associated with killing lesions. Therefore, it was deemed advisable to initiate experiments along this line, and this was done by applying sticky tanglefoot barrier restrictions to the pine stems prior to scale introductions. Two types of barriers were used, one type consisting of only a thin layer of sticky tree tanglefoot smeared around the stem, and the other type made up of an absorbent cotton base wrapped around the stem and about which was placed a ½ inch strip of scotch tape. (See diagram Figure 9). On top of this scotch tape the

Insert Figure 9

sticky tanglefoot substance was applied in order to prevent the tanglefoot from coming in contact with bark surface and causing burn. The tanglefoot barriers were placed at the extremities of the internodes and these were generally effective in limiting the scale, although in a few instances it was observed that some of the insects escaped onto adjoining internodes. The scale was introduced to the restricted internodes by placing egg masses into small thimble-shaped copper screen baskets, these baskets being securely held to the internode by means of a fine copper wire. This work was done at Prescott, Arizona, during the spring of 1938 and at that time thirty-five trees (16 trees of which were on the Wolf Creek Plot 2, and 19 trees on the Copper Basin Divide Plot 3) were artificially infested in this manner. Twenty-two of these trees had first internode restrictions (Figure 10), and fourteen had the second internodes

Insert Figure 10

restricted by means of the tanglefoot band method. The gross results of these tanglefoot infestations are given in Tables 2 and 3.

Insert Tables 2 and 3

During the summer of 1939 fifty of the 1,075 internodes originally infested with scale were cut and taken into the laboratory at Prescott for examination. Each internode was figured or diagrammed to actual size on a piece of drawing paper and measured off into linear inches. The copper baskets and tanglefoot barriers were removed from the internodes and the needles cut off rather short, thus making it possible to observe the infestation of scale under the low power binocular microscope. Preadult scale counts were then made. After the scale counts were completed, the internodes were carefully sliced with a pocket knife so as to determine the exact position of the primary lesion responsible for the death of the twig (see diagram, Figure 9).

The cotton-scotch-tape-tanglefoot band restrictions were about forty-two percent more effective than when the sticky tanglefoot substance was used alone. The scale larvae apparently preferred to settle under the cotton bands because it afforded them some protection. As many as 225 preadults scales of Matsucoccus vexillorum have been observed under one of these cotton-scotch-tape-tanglefoot bands! The results of the scale counts made on the fifty tanglefoot internode restrictions indicate that when there is an average population density of 100 preadult scales per linear inch of stem, with diameters of from ½ to ¾ inches, there will be associated with these insects primary lesions that kill the branch (see diagram, Figure 9). When the scale insects are distributed and feed evenly around the stem, fewer individuals are required to form a complete lesion.

In nature when populations of Matsucoccus vexillorum scale become great enough to be lethal to the branch,,the numbers of feeding preadults are rather evenly distributed on all of the internodes, and primary lesions commonly occur on the third, fourth, fifth and sixth internodes as well as on the younger growth. In the case of the tanglefoot band studies, however, a concentration of scale has been restricted to one portion of the stem sufficiently great to cause death to that particular internode as well as to the younger growth beyond it. The needles immediately behind the primary lesion, within the tanglefoot restrictions, remain alive and green, while those beyond this lesion die (Figure 11).

Insert Figure 11

DEMONSTRATION EXPERIMENTS

The first tests to determine the relation of Matsucoccus vexillorum scale to flagging were done during April 1936, by Dr. Harold Morrison of the Division of Insect Identification, and Dr. A. S. West of the Division of Forest Insects. At that time ten ponderosa pine trees were artificially infested with this scale. The scale insects used for this work were collected from heavily flagged trees in the forest and were introduced to the experimental trees by placing scale egg masses, still intact with the nodes, into small thimble-shaped copper screen baskets and fastening these securely on the twig by means of a fine copper wire (Figure 12). Dr. Morrison was responsible for

Insert Figure 12

this technique and also for ideas as to how the test should be conducted. A total of 220 twigs were grossly infested, and during the following season (1937) 45.5 percent of these infested twigs flagged. In 1938, five additional twigs on these same trees flagged, and during 1939 four more flagged, thus indicating that as the infestation of scale continues to build up and become great enough, flagging will ultimately result.

In the spring of 1937 the author artificially infested fifteen scale and flag free, ponderosa pines on the Prescott National Forest. On some of these experimental trees the scale egg masses were introduced to the branches by means of a camels-hair brush, while on the remainder the copper screen wire baskets were employed. In the early spring of 1938, before there was much evidence of branch flagging, each infested branch was carefully examined in the field by use of a 10X power hand lens to determine the population density of preadult scales on each branch. Three population density classifications were set up as follows: heavy, medium, and light. The results of this artificial infestation work are included in Table 4.

Insert Table 4

The interesting thing about these population forecasts is that such a large percentage (80%) of those branches having heavy infestations of scale flagged, whereas, those having only a light population, or no scale, did not flag at all. The population density of preadult scale affords a convenient indicator for determining whether branches will flag or not. It will be noted from the table that there were many twigs on the experimental trees where only a few, or no scale, became established. This is probably due to the fact that the majority of the trees were infested after the scale eggs had hatched and the young larvae had already moved elsewhere on the infested branches occurring naturally in the forest. Fourteen additional twigs on the experimental trees in this plot flagged during the 1939 season, again substantiating the fact that a continued build-up of scale population ultimately results in branch killing.

During the spring of 1938 it was decided that the most convincing thing to do to prove the definite connection of Matsucoccus vexillorum scale with the flagging of pine branches was to establish some large demonstration plots in which perfectly healthy, vigorous green trees, free of scale and flagging, might be artificially infested with this scale insect. Two experimental plots were laid out on the Prescott National Forest, one (Plot 2) in the Wolf Creek Area, and the other (Plot 3) in the Copper Basin Divide Area. The Wolf Creek plot was, at the time of establishment, in a supposedly flag-free area, although records indicated that some flagging had been observed in this area in years previous. The Copper Basin Divide plot had never, according to the Forest Service records, shown any flagging at all. This plot existed on a divide where winds prevailed in varying intensity throughout the whole year. The trees on this plot were, for the most part, extremely vigorous types. On the Wolf Creek Plot 2, ninety trees were artificially infested with Matsucoccus scale (21 of these trees were given to the Office of Forest Pathology for their culture work), and on the Copper Basin Divide Plot 3, sixty trees were artificially infested. A total of 1,675 individual branches were originally infested with scale, although actual records were taken on only 1,330 branches. Those trees given to Pathology are not discussed in this bulletin. Tables 5 and 6 give the results of this artificial infestation

Insert Tables 5 and 6

work. It will be noted from these tables that the percent of flagged branches is not great, although it must be kept in mind that there will no doubt be a continued build-up of the population of scale insects, and when the population becomes sufficiently great, more flagging will result. This has already been demonstrated in the case of the preliminary studies on artificial infestations initiated in 1936 and 1937. Perhaps in time branches, other than those originally infested on these trees in Plots 2 and 3, will flag as a result of scale migrations. Figures 13 and 14 show the extent of flagging

Insert Figures 13 and 14

on some of these experimental trees in the Copper Basin Divide Plot 3.

In the Lynx Creek Plot 4, eighty naturally infested and flagged trees were marked, and 231 twigs, with adult females and egg masses of varying population intensities, were tagged for future observations. The results of this experiment are given in Table 7. It will be noted from this

Insert Table 7

table that it was possible to predict flagging of seventy-two percent of the branches that possessed heavy populations of adult females and egg masses. Using this stage as a criterion in determining whether a green branch will flag during a given length of time is not as exacting as when the preadult scale population is used as an index. This is probably due to the fact that the preadults have completed their development and the full complement of damage can be ascertained more accurately. In the case of the egg masses, any factor such as predators, or varying climatic conditions, would, no doubt, have a deterrent effect as to the ultimate population of scale on a branch.

NATURAL CONTROL

Although quantities of branches heavily infested with Matsucoccus vexillorum scale were held in the insectary for parasite and predator recovery, few were secured. Only two predators, a ladybird beetle, Scymus sp., and a green lacewing, Chrysopa sp., were recovered. These predators were only occasionally observed in nature and it was quite evident that they played a minor part in the control of this scale insect.

The principal governing natural control factor is the flagged branches on which many hundreds of scale insects have settled. On the basis of extensive scale population counts on both flagged and green twigs (see Table I) it is reasonable to assume that once the scale population has built up to the extent that the branch dies, the scales, as a consequence, perish also. This very thing was pointed out as early as April 1936 by Dr. F. C. Craighead in a Prescott field conference, and was later included in a report sent to the Berkeley Headquarters. Out of a total of 5,669 scales counted on flagged twigs, 5,302 were dead. On the green twigs the condition is just the reverse. Out of 2,328 scales counted only 511 preadults were dead, and this appears to be nothing more than the natural mortality of the insect, causes unknown.

EFFECT OF FLAGGING UPON PINE TREES

Flag counts made during the summer of 1938 and 1939, on the eighty experimental trees on the Lynx Creek Plot 4, indicate that trees heavily flagged one year will flag lightly the following year. For example, on experimental tree number 5 in this plot, one hundred and fifty-two flags were counted in 1938, while only twenty flags were observed during the summer of 1939. This shows a decrease in flagging of approximately eighty-six and eight-tenths percent. Other trees in this plot show about the same percent decrease in flagging, although the general average for all trees was not this great. On some of the trees in this plot there was a slight increase in flagging during 1939.

Evidence, as a result of field observations on the Prescott National Forest, indicates that flagging causes no serious permanent damage to the timber stands as a whole, insofar as protective cover is concerned. Although certain areas have shown considerable damage in the past, these same areas now show but little evidence that individual trees will succumb to the scale damage. However, field observations give every reason to believe that the flagging of terminals and the repeated partial lesioning on individual branches is causing considerable reduction in the quality of this potential timber. The reasons for this are quite obvious, viz.; when a terminal flags, an adjacent lateral takes its place, and in many cases this affects the shape of the tree; repeated partial lesioning on any branch causes the member to twist into abnormal positions, and when this occurs on very many branches on a given tree it frequently results in a deformed tree. While no specific studies have been made by this Bureau on growth characteristics, it is highly probable that growth increment is decreased during periods of heavy flagging.

SUMMARY

A conspicuous type of branch killing or branch flagging, commonly known as"twig blight", has been observed for the past 20 or 25 years on ponderosa pine (Pinus ponderosa var. scopulorum Englemann) trees in Arizona, particularly around the vicinity of Prescott.

Historically the actual cause of this tree disturbance was unknown for many years. In May, 1935, the presence of a margarodid scale insect, Matsucoccus vexillorum Morrison, was discovered on branches of pine trees at Prescott, Arizona.

The branch flagging of the pines on the Prescott National Forest is usually first noticeable in early spring. The needles fade to a light pea-green color, gradually droop, and finally turn yellow colored and die.

When dying branches are cut into, there will be observed at least one primary lesion, usually impregnated with pitch, that completely girdles the branch.

The only known host of this scale insect is Pinus ponderosa var. scopulorum Englemann. Matsucoccus vexillorum Morrison is rather generally distributed throughout the range of this tree in the forested areas of Arizona and New Mexico.

Seasonal life history records of Matsucoccus vexillorum Morrison scale indicate that there is a motile adult female and a winged male emerging during early spring. The adult females settle at the nodes of the branches, secrete wax and lay eggs. There are two appendage-stage larvae developed during the summer, and an intermediate or apodous preadult scale formed in the fall that overwinters on the pine branches under the bract enclosing the needle base. A year's time is required for this species of Matsucoccus scale to complete its life history.

On the basis of histological preparations, it has been noted that this scale insect obtains its food from storage cells of the cortex area.

There is a necrosis of plant cells produced by the feeding activities of aggregations of this scale insect. Histological preparations show an internal breakdown of the cell contents and cell wall disintegration.

The population density of scale insects on flagged twigs is over twice that on green twigs.

When there is an average population density of one hundred pre-adult scales per linear inch of stem, with diameters of from ½ to 3/4 inches, there will be associated with these insects primary lesions that kill the branch. When the scale insects feed evenly around the stem, fewer individuals are required to form a complete killing lesion. Flagging is the result, however, of a generally high population density of Matsucoccus scale.

Artificial infestation experiments initiated during the spring of 1936, 1937 and 1938 resulted in a high percentage of flagged twigs where heavy populations of scale became established. Artificially infested twigs may flag several years later when the population of scale becomes great enough to be lethal to the branch.

The principal governing natural control factor is the killed, or flagged branches, on which many hundreds of scale insects have settled, and this accounts for the fluctuations of flagging throughout successive years.

Evidence, as a result of field observations on the pine forests in Arizona and New Mexico, indicates that flagging causes no serious permanent damage to the timber stands as a whole. Although certain areas have shown considerable flagging in the past, these same areas now show but little evidence that individual trees will succumb to the scale damage. Any attempt directed toward the control of this scale insect may be considered as impractical.